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Shin clearance in the Hawk Mk115

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In conducting the research described in this report, the investigators adhered to the policies and procedures set out in the Tri-Council Policy Statement: Ethical conduct for research involving humans, National Council on Ethics in Human Research, Ottawa, 1998 as issued jointly by the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council of Canada and the Social Sciences and Humanities Research Council of Canada.

Abstract

In April 2006, the Canadian Forces (CF) transitioned to a new anthropometric selection standard for pilots. The new standard bases acceptance and rejection on whether individuals are physically compatible with the cockpits of all current aircraft; the previous standard was not aircraft-specific. As a result, cockpit compatibility assessments are not currently available for student pilots who were admitted under the previous standard and are now undergoing training. In July 2007, a pilot slated to train on the Hawk suspected he was too large for the cockpit. This prompted a series of events including an anthropometric assessment of current Hawk pilots and a review of the screening process and limits currently in place.

Ten pilots from 15 Wing and an external pilot were recruited to participate in a field trial designed to assess the shin clearance limits of the Hawk Mk 115. Clearance measurements between the shins and the main instrument panel were taken with the seat completely down or up, in summer and winter clothing. The minimum distance between the shins and the instrument panel was recorded with the rudder pedals in neutral and full left positions. In addition, the largest subject was assessed in the Hawk ejection trainer. The objective was twofold: 1) to observe the effect of seat movement on shin clearance and 2) to determine whether the trainer could be used as a cockpit compatibility assessment tool.

The results indicate that there is scope for a small increase in the current anthropometric limits with respect to shin clearance. However, the significance of this increase in terms of population accommodation depends on which option is retained. The recommended option would provide a risk-balanced limit that accepts a reduced ejection clearance zone between the knees and the rear-view mirrors. This would increase accommodation by about 2.5%. It was also determined that the ejection simulator was not sufficiently similar to the actual cockpit to be used as a cockpit compatibility assessment tool.

Résumé

En avril 2006, les Forces canadiennes (FC) ont adopté une nouvelle norme de sélection anthropométrique pour les pilotes. La nouvelle norme base l'acceptation ou le rejet des candidats selon qu’ils sont physiquement compatibles avec les postes de pilotage de la flotte; la norme précédente n'était pas aussi spécifique. En conséquence, la compatibilité des élèves pilotes présentement en formation n’est pas disponible pour ceux et celles qui ont été admis sous la norme précédente.

En juillet 2007, un pilote en voie d’être formé sur le Hawk soupçonnait qu'il était trop grand pour le poste de pilotage. Il a été envoyé à RDDC Toronto pour une évaluation en vertu de la nouvelle norme. Les résultats ont confirmé son incompatibilité. Cette décision a conduit à une série d’actions dans 15ème Escadre, y compris une évaluation de tous les pilotes de Hawk actuels afin d’identifier toute incompatibilité, un examen du processus de sélection, et une revue des limites actuelles.

Dix pilotes de la 15ème Escadre plus un pilote externe ont été recrutés pour participer à un essai sur le terrain pour évaluer les limites d’accommodation du Hawk Mk 115. Les tests ont consisté à mesurer la distance entre les tibias et panneau principal avec palonniers neutre ou plein gauche. Les essais ont été effectués avec le siège vers le bas ensuite et vers le haut, et en vêtements d’été et d'hiver. Des tests supplémentaires ont été effectués en utilisant le plus grand des sujets qui consistaient à effectuer des éjections simulées dans le simulateur d’éjection du Hawk. L'objectif était double: 1) d'observer l'effet du déplacement du siège sur le tibia et 2) afin de déterminer si le simulateur pourrait être utilisée comme outil d'évaluation de compatibilité du poste de pilotage.

Les résultats indiquent qu'il est possible d'augmenter légèrement les limites anthropométriques actuelles. Toutefois, l'importance de cette augmentation en termes d’accommodation de la population dépend de l'option qui est retenue. L'option recommandée fournirait un risque équilibré en acceptant une diminution de la zone de dégagement entre les genoux et les rétroviseurs. Cela augmenterait l’admissibilité d'environ 2,5% pour les hommes (aucun effet sur les femmes). Il a également été déterminé que le simulateur d'éjection n'était pas suffisamment fidèle à la réalité pour être utilisé comme outil d'évaluation.

Executive summary

Shin clearance in the Hawk Mk115:

Pierre Meunier; DRDC Toronto TM 2007-129; Defence R&D Canada – Toronto; January 2008.

Background: In April 2006, the Canadian Forces (CF) transitioned to a new anthropometric selection standard for pilots. The new standard bases acceptance and rejection on whether individuals are physically compatible with the cockpits of all current aircraft; the previous standard was not aircraft-specific. As a result, cockpit compatibility assessments are not currently available for student pilots who were admitted under the previous standard and are now undergoing training.

In July 2007, a pilot slated to train on the Hawk suspected he was too large for the cockpit. He was sent to DRDC Toronto for assessment under the new standard. The results confirmed his incompatibility. This prompted a series of events in 15 Wing including an anthropometric assessment of all current Hawk pilots to determine any further incompatibilities, and a review of the screening process and limits currently in place.

Under the current standard, long-legged Hawk pilots can be rejected either due to shin clearance or ejection clearance of the rear-view mirrors. The shin clearance limits were established by British Aerospace Systems (BAe) and included in the Hawk's Release to Service document. The ejection clearance limits were established by a DRDC Toronto study in 2000. The purpose of this study was to establish risk-balanced limits for leg clearance.

Ten pilots from 15 Wing plus an external pilot were recruited to participate in the field trial. The tests consisted in measuring the distance between the shins and the main instrument panel while maintaining neutral or full left rudders. The tests were conducted with the seat down then up, and in summer and winter clothing ensembles.

Additional tests were carried out using the largest subject, which consisted in performing simulated ejections in the Hawk ejection trainer. The objective was twofold: 1) to observe the effect of seat movement on shin clearance and 2) to determine whether the trainer could be used as a cockpit compatibility assessment tool.

Results: The results indicate that there is scope for a small increase in the current anthropometric limits with respect to shin clearance. However, the significance of this increase in terms of population accommodation depends on which option is retained. The recommended option would provide a risk-balanced limit that accepts a reduced ejection clearance zone between the knees and the rear-view mirrors. This would increase accommodation by about 2.5% for males (no effect on females).

It was also determined that the ejection simulator was not sufficiently similar to the actual cockpit to be used as a cockpit compatibility assessment tool. However, the experiment was useful to ascertain that the shins did not get any closer to the main instrument panel as the seat went up the rails.

Significance: This study concludes that the current anthropometric limits, both from BAe and DRDC Toronto, are slightly more conservative than they need to be. A small but significant increase is warranted on a risk-balance basis that would enable more pilots to train and progress to the CF-188, which is more spacious than the Hawk.

Sommaire

Shin clearance in the Hawk Mk115:

Pierre Meunier; DRDC Toronto TM 2007-129; R & D pour la défense Canada – Toronto; Janvier 2008.

Rappel des faits : En avril 2006, les Forces canadiennes (FC) ont adopté une nouvelle norme de sélection anthropométrique pour les pilotes. La nouvelle norme base l'acceptation ou le rejet d'un candidat selon qu'ils sont physiquement compatibles avec les cockpits de la flotte; la norme précédente n'était pas aussi spécifique. En conséquence, la compatibilité des élèves pilotes présentement en formation n'est pas disponible pour ceux et celles qui ont été admis sous la norme précédente.

En juillet 2007, un pilote en voie d'être formé sur le Hawk soupçonnait qu'il était trop grand pour le poste de pilotage. Il a été envoyé à RDDC Toronto pour une évaluation en vertu de la nouvelle norme. Les résultats ont confirmé son incompatibilité. Cette décision a conduit à une série d'actions dans 15ème Escadre, y compris une évaluation de tous les pilotes de Hawk actuels afin d'identifier toute incompatibilité, un examen du processus de sélection, et une revue des limites actuelles.

En vertu de la norme actuelle, les individus à longues jambes peuvent être rejetés en raison du manque d'espace entre le tibia et le panneau de bord ou de l'interférence entre le genou et les rétroviseurs à l'éjection. Les limites pour le tibia ont été établies par British Aerospace Systems (BAe) et sont inclus dans les documents d'entrée en service du Hawk. La limite d'éjection ont été établies par une étude de RDDC Toronto en 2000. Le but de l'étude actuelle était d'établir des limites qui balancent les risques.

Dix pilotes de la 15ème Escadre plus un pilote externe ont été recrutés pour participer à l'essai sur le terrain. Les tests ont consisté à mesurer la distance entre les tibias et panneau d'instruments principal avec palonniers neutre ou plein gauche. Les essais ont été effectués avec le siège vers le bas ensuite et vers le haut, et en vêtements d'été et d'hiver.

Des tests supplémentaires ont été effectués en utilisant le plus grand des sujets qui consistaient à effectuer des éjections simulées dans le simulateur d'éjection du Hawk. L'objectif était double: 1) d'observer l'effet du déplacement du siège sur le tibia et 2) afin de déterminer si le simulateur pourrait être utilisée comme outil d'évaluation de compatibilité du poste de pilotage.

Résultats : Les résultats indiquent qu'il est possible d'augmenter légèrement les limites anthropométriques actuelles. Toutefois, l'importance de cette augmentation en termes d'accommodation de la population dépend de l'option qui est retenue. L'option recommandée fournirait un risque équilibré en acceptant une diminution de la zone de dégagement entre les genoux et les rétroviseurs. Cela augmenterait l'admissibilité d'environ 2,5% pour les hommes (aucun effet sur les femmes).

Il a également été déterminé que le simulateur d'éjection n'était pas suffisamment fidèle à la réalité pour être utilisé comme outil d'évaluation. Toutefois, l'expérience a été utile pour vérifier que les tibias ne se rapprochent pas du panneau d'instruments principal lors de la montée du siège.

Importance : Cette étude conclut que les limites actuelles anthropométriques, à la fois de BAe et RDDC Toronto, sont un peu plus conservatrices qu'elles ne pourraient l'être. Une légère augmentation semble justifiée d'autant plus qu'elle permettrait de former plus de pilotes pour le CF - 188, qui est plus spacieux que le Hawk.

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1 Introduction

1.1 Earlier assessment of the Hawk

A detailed anthropometric study was conducted in July 2000 (Meunier, 2001) to determine the limits of accommodation of the Hawk. The study identified restrictions related to minimum eye height and maximum leg length. The study found disaccommodation of tall individuals with respect to ejection clearance (knees contacting the rear view mirrors in the front cockpit) and shin clearance (shin contact with instrument panel). Ejection clearance was the more restrictive of the two, mainly because of uncertainty surrounding the submarining effect (sliding out of the seat), an effect that was known to occur in (older) ejection seats and restraint systems.

A surprising fact of the 2000 trial (Meunier, 2001) was that two of the test subjects were unable to actuate the rudder pedals due to interference of their shins with the main instrument panel. This effectively reduced the number of data points that could have been used to establish an accurate accommodation limit. Since the results of independent studies conducted in the U.K. by BAe Systems were found to agree fairly well with those of the 2000 trial (Day, 2000a, 2000b; Mitchell, 2000), the report proposed the adoption the results derived by (Day, 2000a). An equation representing those results was included in the new pilot selection screening standard. The same limitations were included in BAe Systems Release to Service document (BAe_Systems, 2000).

1.2 15 Wing

In March 2007, one of the 15 Wing student pilots assigned to the Hawk for training had misgivings about the small size of the cockpit and suspected he might be incompatible. He had been admitted under the old anthropometric selection standard, which, contrary to the new standard, had no aircraft-specific compatibility information. He was flown to DRDC Toronto for a formal assessment under the new anthropometric selection standard for pilots, which was adopted in April 2006 (Lt-Gen Lucas, 2005). The assessment confirmed that he was indeed outside the safe limits of accommodation for that cockpit.

This incident caused 15 Wing to review its procedures and reassess all of its Hawk pilots, most of who had gone through aircrew selection prior to the advent of the new standard. DRDC Toronto was asked to send a specialist to measure pilots at 15 Wing (Moose Jaw) and 4 Wing (Cold Lake) in May 2007 to perform the measurements and assess their compatibility.

Of note were the results of an experienced Hawk pilot whose measurements were deemed outside BAe Systems' Release to Service documentation. The fact that this individual had a great deal of experience as a Hawk pilot (UK experience) was an indication that the implemented limits might be a little too conservative and warranted further investigation. He was sent to DRDC Toronto for a detailed assessment in accordance with the new anthropometric standard, but the results were the same.

A detailed account of 15 Wing's situation with respect to anthropometric issues (Foster, 2007) recommended the establishment of a "risk-measured" limit that was "not overly conservative but

provide(s) appropriate safety to aircrew". The decision was therefore made to re-assess the Hawk cockpit and focus on the limits of accommodation for shin clearance.

1.3 Objective

The present study's objective was to reassess shin clearance in the Hawk in order to provide the definitive limits of compatibility. The present report details the field trial that was conducted in July (2007) in Moose Jaw, work that was sponsored by Air Force Training (1 Canadian Air Division).

2 Method

2.1 Subjects

Ten subjects were selected from a list of pilots from 15 Wing Moose Jaw (instructors and students), with an eleventh coming from another organization. The anthropometric characteristics of those individuals were initially obtained from the database of measurements kept at the Central Medical Board (CMB) in DRDC Toronto. The subjects were measured at the start of the accommodation trial in accordance with the definitions in (Chamberland, Carrier, Forest, & Hachez, 1998)) for consistency and accuracy purposes. The measurements of interest, i.e. Buttock-knee length and Knee height sitting, are shown in Table 1 and are plotted relative to anthropometric data from the 1985 survey of aircrew (Stewart, 1985) in Figure 1.

Table 1 Anthropometry of participants

	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**
Knee height, sitting (mm)	548	594	530	574	595	571	591	525	560	539	573
Buttock-knee length (mm)	596	646	625	643	655	619	639	580	613	591	630
Knee height, sitting (percentile*)	25%	87%	8%	63%	87%	58%	84%	6%	42%	15%	61%
Buttock-knee length (percentile*)	32%	90%	71%	88%	95%	63%	85%	15%	55%	26%	77%

* based on 1985 survey of pilots (Stewart, 1985)

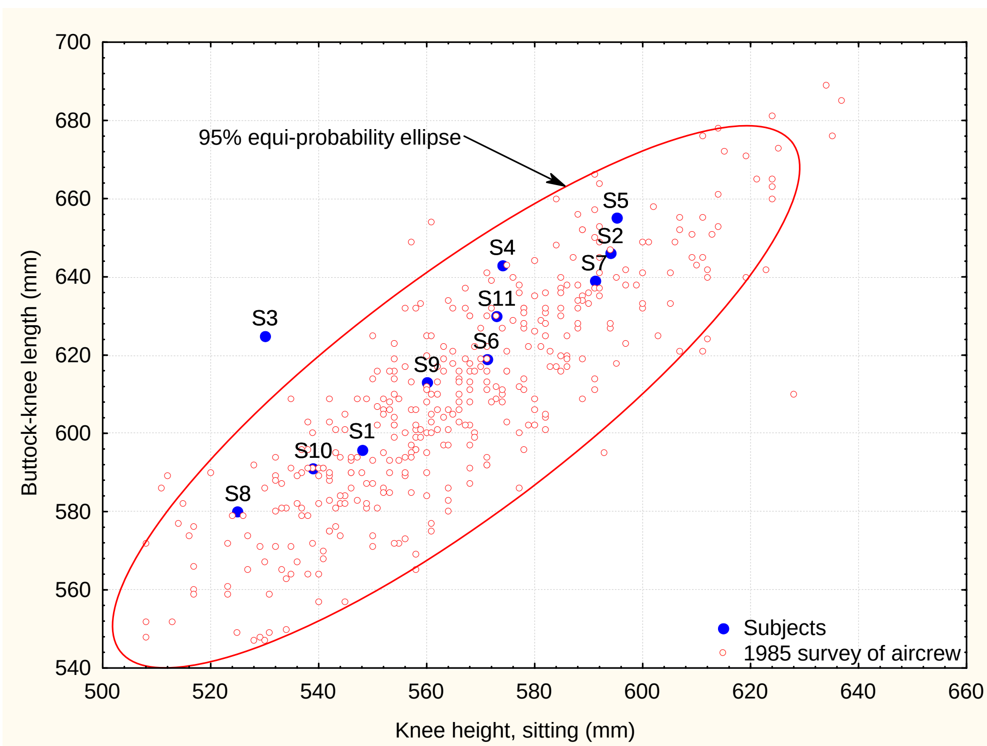

Figure 1 Buttock-knee length vs. Knee height sitting for participants relative to 1985 survey

2.2 Aircraft

Aircraft tail number 218 was used for this assessment.

2.3 Clothing and equipment

Both summer and winter flying gear were worn during the tests. Summer gear included the summer flying clothing, the Beaufort Mk30LC LPSV (Life Preserver Survival Vest), and the STING NFTC g-suit. The winter coverall and jacket were added to the summer dress to complete the winter condition.

2.4 Shin clearance

Since the front and rear seats are geometrically identical, the tests were performed in the front seat only. Clearance measurements were taken in the seat fully down and fully up. The minimum distance between the shins and the instrument panel was recorded to the nearest millimetre using a steel tape measure. In each case, the rudder pedal carriage was adjusted as far forward as possible while still allowing full rudder and brakes to be applied without the subject moving his hips or sliding in the seat. Clearance to both shins was measured when the rudders were neutral and during full left rudder. Finger pressure was applied to the shins to compress the loose summer or winter clothing.

2.5 Simulated ejections

In addition to cockpit measurements, simulated ejections were performed in the ejection trainer with the largest subject. One of the objectives of this test was to determine whether the ejection trainer could be used as a tool to predict ejection clearance. The other objective was to observe the mechanics, albeit slow motion dynamics compared to a real ejection, of the ejection in conjunction with the action of the leg restraint system. The ejections were recorded using digital video.

3 Results

3.1 Aircraft cockpit results

The distances between the shins and the underside of the instrument panel for each subject and test condition are listed in Table 2. The table shows a range of 18 mm to 125 mm for minimum shin clearance, which is defined as the smallest of the left or right shin distances for a given rudder position.

Table 2 Shin clearance results (mm) for subjects S1 to S11

Clothing	**Seat**	**Pedals**	**Leg**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**
summer	down	neutral	left	76	32	55	30	21	54	26	125	52	95	35
			right	76	30	50	32	21	50	32	140	70	85	45
		full left	left	160	25	85	58	47	78	30	175	83	155	70
			right	70	45	43	40	37	50	60	110	75	75	55
	up	neutral	left	75	32	45	32	35	24	37	85	45	70	45
			right	75	30	45	32	35	28	35	90	57	73	40
		full left	left	97	40	65	71	60	55	60	108	62	100	85
			right	60	40	32	35	25	53	45	80	55	60	50
winter	up	neutral	left	80	20	40	35	30	23	34	80	45	75	50
			right	75	20	35	35	30	25	40	80	60	75	60
		full left	left	98	20	52	72	68	55	70	100	78	97	70
			right	60	26	35	35	18	25	50	75	60	60	50
	down	neutral	left	85	30	52	30	18	35	33	100	60	95	55
			right	88	30	47	30	21	40	40	115	80	90	60
		full left	left	150	20	80	57	35	60	40	170	82	165	85
			right	70	40	45	40	32	40	60	100	75	80	55

A repeated-measures analysis of variance was performed using Statistica 8[1] to examine the effects of Clothing (summer and winter), Seat Position (up and down) and Pedals (full left vs. neutral) on minimum shin clearance. The results, in Table 3, indicate that Seat position was the only factor affecting shin clearance in a consistent way ($p = 0.037$). Interestingly, no effect of pedal actuation was found, indicating that for a given individual, the minimum clearance does not change appreciably over the full range of pedal deflection.

[1] Statsoft Inc

Table 3 ANOVA results for minimum shin clearance

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition SS	Degr. of Freedom	MS	F	p
Intercept	221101.4	1	221101.4	57.58748	0.000019
Error	38394.0	10	3839.4		
CLOTHING	57.3	1	57.3	0.57308	0.466501
Error	999.6	10	100.0		
SEATPOS	1230.0	1	1230.0	5.74674	0.037492
Error	2140.4	10	214.0		
PEDALS	27.3	1	27.3	0.15969	0.697846
Error	1708.6	10	170.9		
CLOTHING*SEATPOS	29.6	1	29.6	1.60358	0.234099
Error	184.3	10	18.4		
CLOTHING*PEDALS	27.3	1	27.3	1.01018	0.338560
Error	270.1	10	27.0		
SEATPOS*PEDALS	17.3	1	17.3	0.28826	0.603074
Error	599.6	10	60.0		
CLOTHING*SEATPOS*PEDALS	3.3	1	3.3	0.15412	0.702869
Error	213.1	10	21.3		

As a result of the ANOVA, the data were pooled with respect to Clothing and Pedals, and analyzed using multiple regression. Buttock-knee length, Knee height sitting, and Seat position were selected as independent variables. The results showed that Buttock-knee length and Seat position were the best predictors of minimum shin clearance.

A closer look at the raw data revealed that the regression lines for seat up and down had different slopes, as illustrated in Figure 2. The two regressions intersected at a Buttock-knee length value of 642 mm. As Buttock-knee length increases from that value, the seat down equation predicts less clearance than when the seat is up. In other words, raising the seat would be beneficial for long-legged individuals. Also, the smallest subject's data, S8, suggests the possibility of non-linearity at that end of the spectrum. Since these data may be considered outliers, they were removed to assess their effect on the maximum Buttock-knee length value. The effect, shown as a dotted line in Figure 2, represents an increase of 4 mm on the maximum Buttock-knee length value (intersection of the line with the 15 mm minimum clearance line), or 663 mm in absolute terms, and a zero-clearance value of 679 mm.

One of the papers by BAe (Mitchell, 2000) states that "for aircrew to aircraft structure a minimum clearance of 15 mm is required for a safe ejection envelope". Based on our results, the "seat down" regression equation predicts that:

1. An individual with a Buttock-knee length of 663 mm is likely to have the required 15 mm clearance, and;

2. Anybody beyond 679 mm would likely have zero shin clearance and would therefore not be able to operate the pedals.

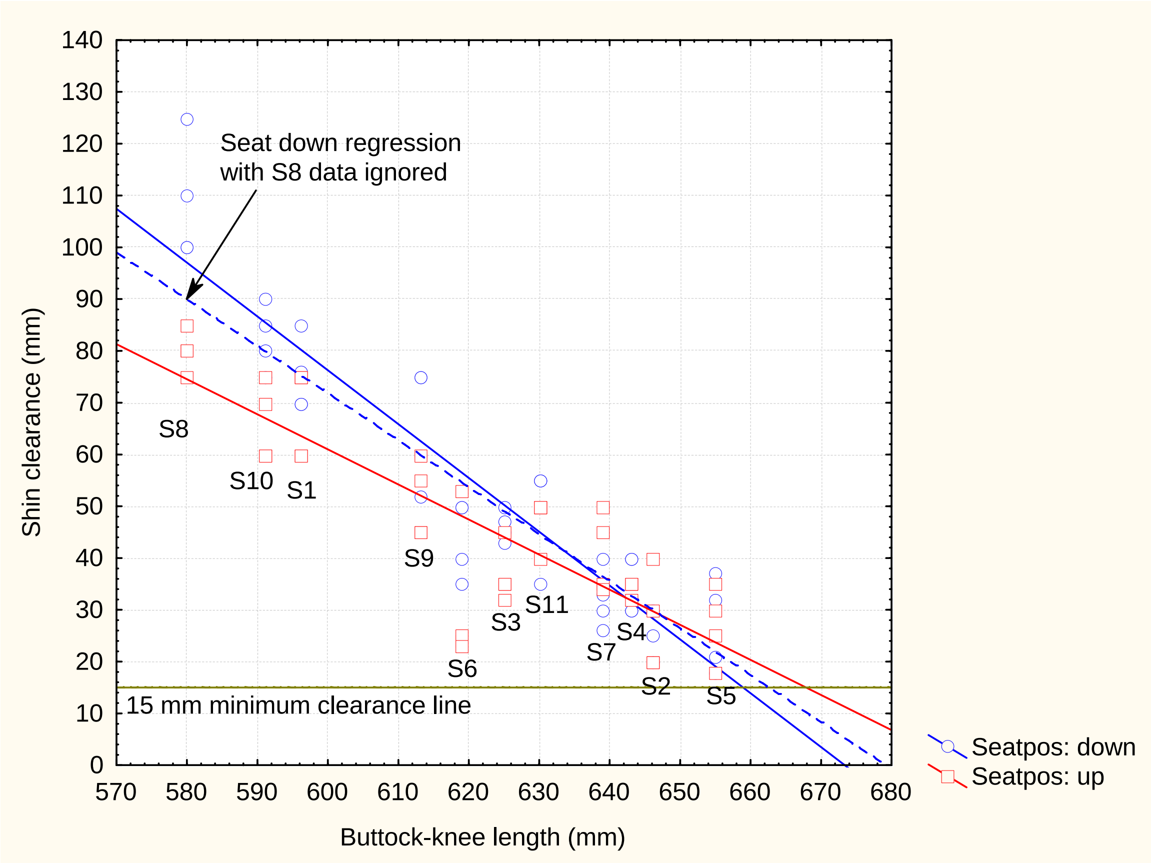

Figure 2 Minimum shin clearances

3.2 Ejection trainer

3.2.1 Cockpit geometry

At first glance, the ejection simulator appears similar enough to the actual aircraft to warrant investigation on whether it could be used in the future as a go/no-go gauge of sorts. On closer look, however, several differences come to light. For instance, the distance between the shins and the MIP for the largest test subject was found to be slightly greater than what was observed in the actual aircraft; 35 mm and 32 mm for the left and right legs compared to 21 mm and 21 mm in the aircraft[2].

[2] . With the seat down, summer clothing, g-suit, no LPSV

Another difference reported was that the rudder pedal action felt considerably different due to a different pedal inclination. This caused the subject's shins to contact the trainer's MIP during full deflection, which was not the case in the real aircraft.

As shown in Table 4, the relationship between the canopy sill and the ejection rails differed by about one degree, with the simulator having the slightly larger angle. Although this may appear like a small difference, it represents about 17 mm over one meter of seat displacement, and would improve clearance by that much as the knees rise above the canopy bow.

Unfortunately, the ejection trainer lacks rear-view mirrors, which are an obstacle in the front seat and the most restrictive item in terms of accommodation. The relative distance between the canopy bow and the seat, compiled in Table 4, reflect this situation. The middle of the canopy bow – with canopy closed – is 15 mm closer in the ejection trainer than in the real aircraft. Since the trainer lacks mirrors, it is not surprising that the aircraft is more restrictive in that area by approximately 55 mm.

Overall, it is clear that the geometry of the ejection trainer does not replicate that of the aircraft well enough to be used as an ejection clearance assessment tool. Therefore, in its current configuration, the ejection simulator should not be used for screening purposes.

Table 4 Comparison between aircraft tail# 218 and the ejection trainer

	Aircraft 218	Ejection trainer	Difference
Canopy Sill Angle (deg)	-13.5	-12.7	0.8
Ejection Rail Angle (deg)	20.0	21.8	1.8
Ejection Rail Angle relative to sill (deg)	33.5	34.5	1.0
Distance from headrest box to:			
middle of canopy bow with canopy open (mm)	735	755	20
middle of canopy bow with canopy closed (mm)	690	675	-15
left mirror (mm)	620	675	55
mirror hinge (solid bracket) (mm)	655	675	20

3.2.2 Simulated ejection

Use of the ejection trainer was viewed as a convenient way of producing an easily observable slow-motion ejection sequence involving a test subject. While considerably slower than the real event, the simulated ejection was still too rapid for the naked eye to observe what actually happens to the shin clearance as the seat moves up the rails. For that reason, the ejections were recorded using a digital camera, which permitted slow-motion playback and frame by frame qualitative analysis.

The video showed a very slight movement forward, perhaps a few millimetres, at the very start of the ejection. It is not clear whether this was a real effect or an artefact of the hydraulic system. The subject reported feeling an initial bump on pulling the ejection handle, and suggested it was an artefact. Beyond the initial bump, careful review of the video indicated that the shins move away from the main instrument panel as the seat moves up. A series of ejections were performed

using various camera angles, all showing fairly conclusively that the shins do not get any closer to the main instrument panel.

4 Discussion

4.1 Analytical versus empirical results

A review of the three reports by BAe Systems shows that there was a progression toward a preferred solution. The first report argued for a safe Buttock-knee length limit of 653 mm (Mitchell, 2000); the second one proposed 648 mm (Day, 2000b); the third report proposed an analytical solution that allows Buttock-knee length values between 645 and 672 mm (Day, 2000a) depending on knee height. The first two reports were based on one subject's results; the initial result was re-analysed in the second report, subtracting 5 mm for clearance. The third report presented the results from two test subjects, but supplemented the empirical results with an analytical solution based on a simplified geometric representation of the leg. It was determined that Buttock-knee length, Knee height sitting, and buttock-heel length were necessary variables to control shin clearance. A table of recommended leg dimensions was provided, which can more succinctly be expressed as follows:

$$Buttock\_knee\_lth + 0.24 * (knee\_height\_sitting) \leq 795 \text{ mm} \quad (1)$$

In contrast, the current study was entirely empirical. Its conclusions were based on the statistical analysis of results coming from 11 pilots under various clothing and seat conditions with two rudder pedal positions. The only variables of importance for predicting shin clearance were Buttock-knee length and seat position. A safe limit of 663 mm was proposed based on the requirement to have a 15 mm clearance between the shins and the bottom of the main instrument panel. Extrapolation of the results showed that the threshold of incompatibility – i.e. the point at which the shins contact the panel – is around 679 mm. These values are consistent with the previous Hawk evaluation (Meunier, 2001), where an individual with 658 mm Buttock-knee length had 15 mm shin clearance and individuals with 678 mm and 690 mm were unable to actuate the rudder pedals.

One of the important differences between the BAe analytical solution and the present empirical study is the fact that Knee height sitting is used in the former but not the latter. One of the reasons for this may be the fact that the ratio of Buttock knee length to Knee height sitting was relatively constant in our test participants and did not allow us to explore the effect of various ratios on clearance.

Figure 1 shows that most participants lie along a fairly narrow path, almost in a straight line. From the BAe analysis, the magnitude of the Knee height sitting effect is about 24% based on the slope. However, because of the correlation between Buttock-knee length and Knee height sitting in our subjects, the effect is further reduced in absolute terms. Figure 3 shows the BAe equation relative to a population of aircrew. From the intersection of the 95% probability ellipse and the equation, i.e. points A and B, it is found that the effect of Knee height sitting corresponds roughly to +- 5 mm in Buttock-knee lengths over the entire range. Over the narrow range of test subjects of this study, largely encompassed by the two long lines in Figure 3, this effect is reduced to negligible levels of approximately +- 2 mm. Compared to the variability due to individual sitting postures, measurements errors, etc., it is not surprising that such a small effect was statistically undetectable.

Regardless of statistical significance, it is difficult to argue against Knee height sitting having an effect on shin clearance from a conceptual standpoint; the geometric analysis is compelling. Furthermore, the empirical data collected in this study appears to fit the theory quite well. For instance, considering that the line A-B in Figure 3 is an equidistant shin clearance line, meaning that any individual on that line would have the same shin clearance, any two points on that slope should have the same clearance. Referring to Figure 3, this means that subjects S4 and S7 should have the same shin clearance, and subjects S3 and S6 should not differ by much, with S6 having slightly less clearance than S3 in spite of the fact that his Buttock-knee length is smaller. Indeed, the data in Figure 2 appears to support the theory.

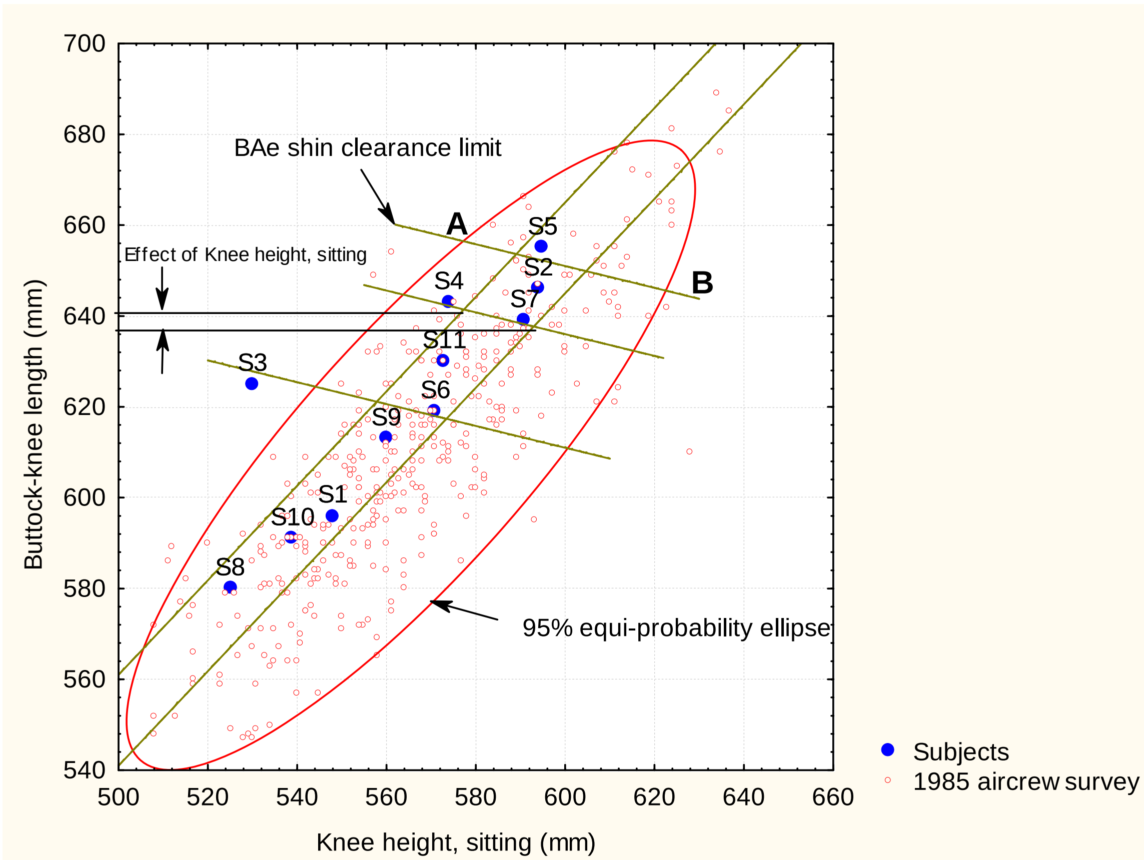

Figure 3 BAe limit relative to a population of CF aircrew

4.2 Ejection clearance

Is shin clearance a question of ejection safety or simply a question of flight safety – i.e. having full control of the pedals throughout its full range of motion? Tests have shown that for Buttock-knee lengths greater than 640 mm, the shins do not get any closer to the main instrument panel as the seat moves up its rails. This was also observed in the ejection trainer tests. Therefore, it must be concluded that since shin clearance is not affected by seat ejection it should not be considered

an ejection safety issue but rather a flight safety issue; one must be able to maintain full rudder deflection in summer and winter clothing without impediment.

The restrictions due to shin clearance must nevertheless be balanced against those imposed by ejection clearance. Mitchell (2000) states that the “Ejection Seat Escape envelope has been designed to enable a 99%ile RAF (as per RAF Anthropometry Survey 1971, Technical Report 73083), to eject without infringing into the minimum (15 mm) pilot structure clearance”. He implies that the 99%ile for Buttock-knee length, a value of 671.7 mm, still has an allowable clearance of 15 mm between the pilot and the aircraft structure. Seat pull-through tests conducted in 2000 (Meunier, 2001) do not support this claim when it comes to clearing the rear-view mirrors. The test results indicated that in summer clothing, an individual with a 671 mm in Buttock-knee length would brush against the mirrors - i.e. zero clearance – rather than having a 15 mm clearance, and in winter clothing, this value decreases to 663 mm (Figure 4). It is possible that the mirrors themselves, which are hinged and movable up and down, were not considered part of the aircraft structure. The mirror hinges, which are solidly attached to the canopy bow, are somewhat farther from the ejection path of the knees and could have been deemed the limitation. Figure 4 confirms that a person of 671.7 mm would indeed have the required 15 mm minimum clearance between the knee and the hinge in summer and winter clothing.

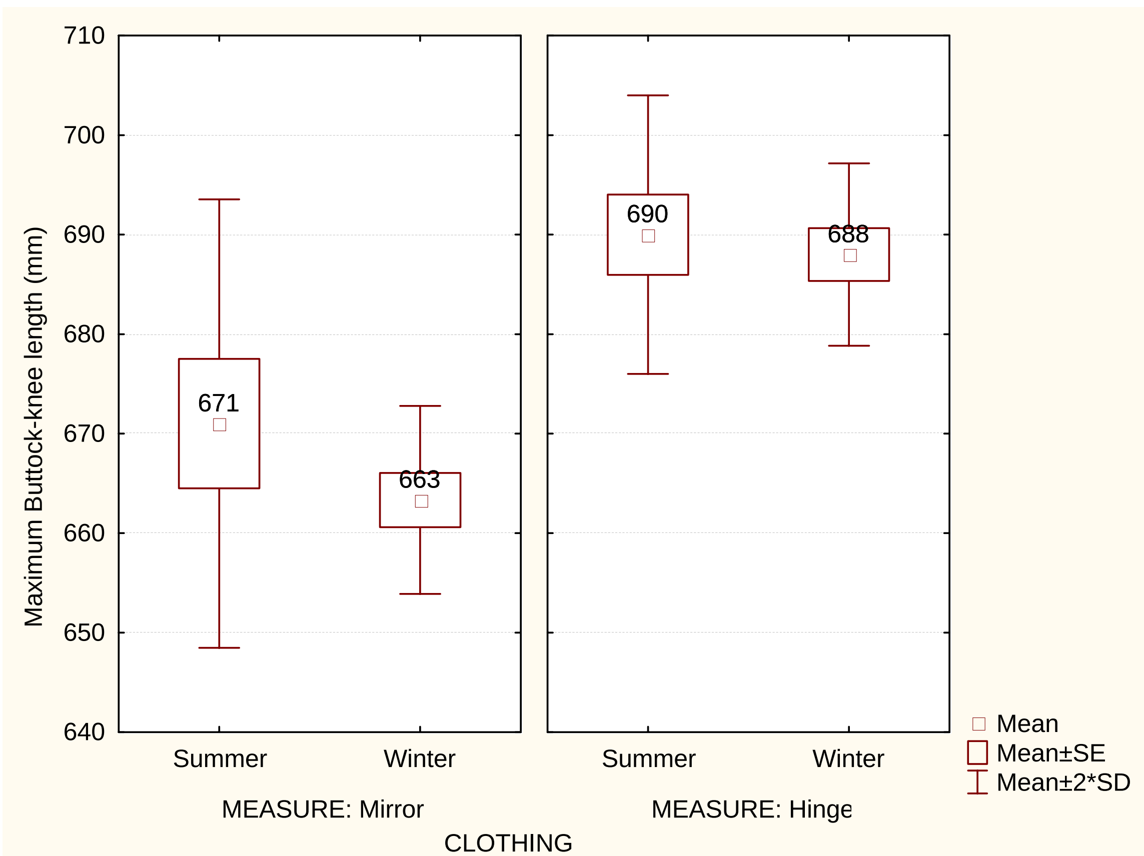

Figure 4 Ejection clearance results from Meunier (2000)

4.3 Options analysis

4.3.1 Current limits

The current pilot selection limits include a shin clearance assessment based on the BAe equation and a maximum Buttock-knee length value of 650 mm based on clearance of the mirrors during ejection. The rejection zone, represented by the shaded area in Figure 5, is made up of almost equal contributions from the two limits, each one taking turns in excluding a portion of the population. The problem with the current limits is that they appear to be slightly conservative, based on the results of this study.

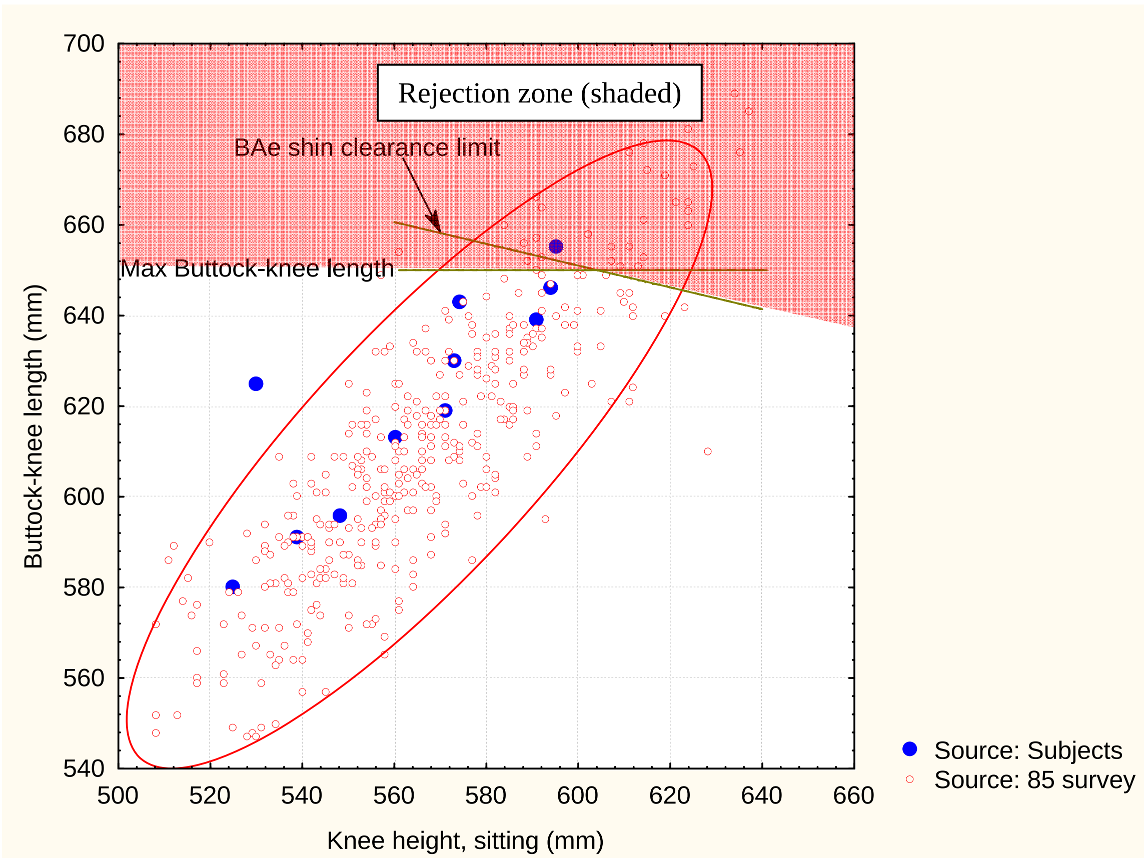

Figure 5 Current limits and rejection zone

4.3.2 Option 1

The combination of Buttock-knee length and Knee height sitting proposed by BAe has considerable merit as discussed in 4.1. Option 1 would propose the addition of 5 mm to the inequality, as shown in Equation 2, in order to better fit the empirical data collected in both this study and that of 2000. This change could be viewed as a calibration of the analytical solution.

$$Buttock\_knee\_lth + 0.24*(knee\_height\_sitting) \leq 800 \text{ mm} \quad (2)$$

The proposed limit, displayed in Figure 6, would be inclusive of all test participants, all of whom had more than 15 mm clearance in all clothing and seat conditions. However, the effect of this change on population accommodation, highlighted as the new inclusion zone, would be overshadowed by the ejection clearance limit for the mirrors. In practical terms, Option 1 would be comparable to the status quo.

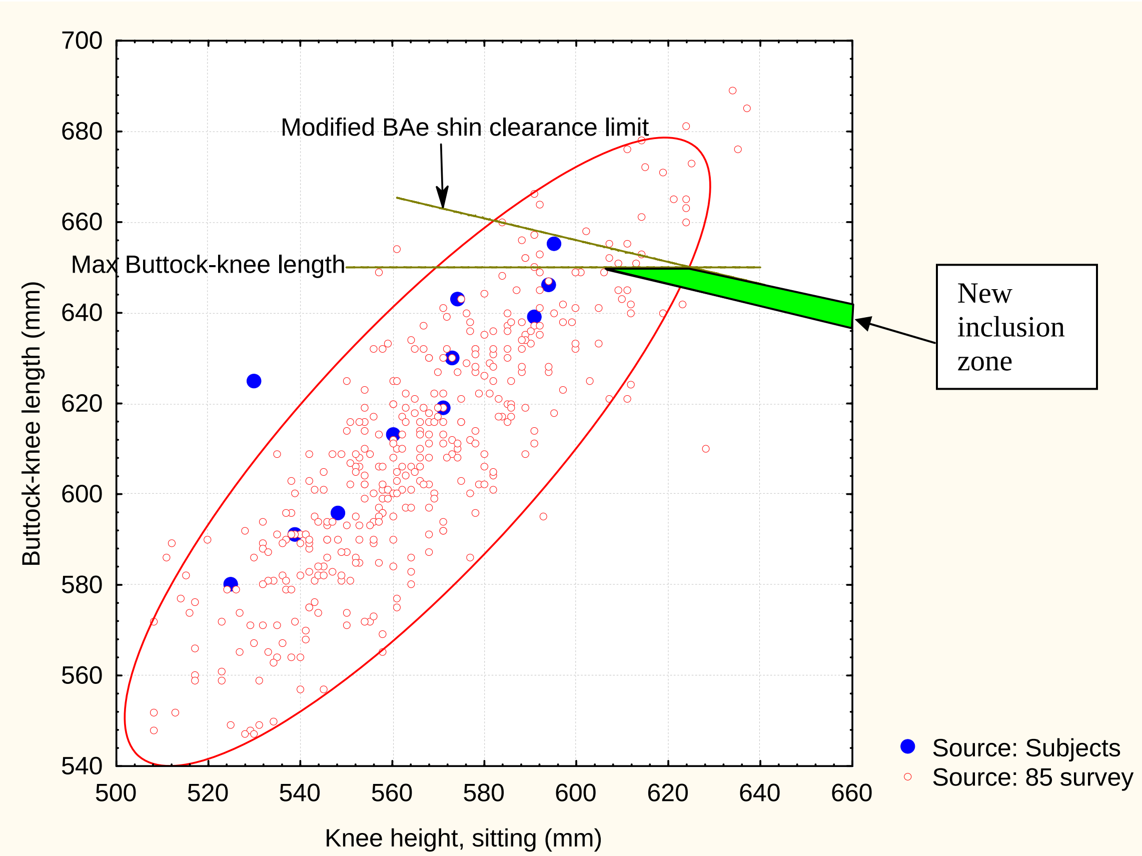

Figure 6 Option 1 limits

4.3.3 Option 2

Option 2 re-examines the need to clear the mirrors themselves. Indications are that BAe does not consider the rear-view mirrors to be an ejection hazard. Evidence of this is that 1) they have not put any restriction other than the table (or equation) defining shin clearance limitations in their Release to Service document, and 2) the 99 percentile value of 671.7 mm corresponds to a 15 mm clearance of the mirror hinges, as discussed in 4.2, and not the mirrors themselves.

If the mirror hinges become the limitation, then, the combination of the modified BAe limit with the new ejection clearance limit will result in a significantly expanded inclusion zone, as displayed in the shaded area of Figure 7. Interestingly, it is clear from Figure 7 that shin clearance is the only factor driving acceptance and rejection; the ejection clearance limit (or “Max Buttock-knee length based on mirror hinges”) does not come into play at all. Looking at the graph, the longest Buttock-knee length afforded by the shin clearance limit is around 660 mm at the 95%

probability level (intersection of the modified BAe equation with the 95% probability ellipse), and around 662 mm at a 99% probability level (not shown). This coincides almost exactly with the 663 mm zero-clearance limit found for the worst-case clothing condition (winter) displayed in Figure 4. Thus, the shin clearance limit would appear to be a suitable limit for ejection clearance as well.

In terms of the effect of this change on population accommodation, the proposed 5 mm increase would result in an extra 2.5% of males being admissible when compared to the current situation. This comes at the risk of having the very largest individuals grazing the mirrors on ejection, provided there is no submarining effect. However, this risk should be very low considering the low percentage of individuals of that size combined with a low probability of ejection. Thus, this option would appear to provide a good “risk-measured limit” as requested by 15 Wing.

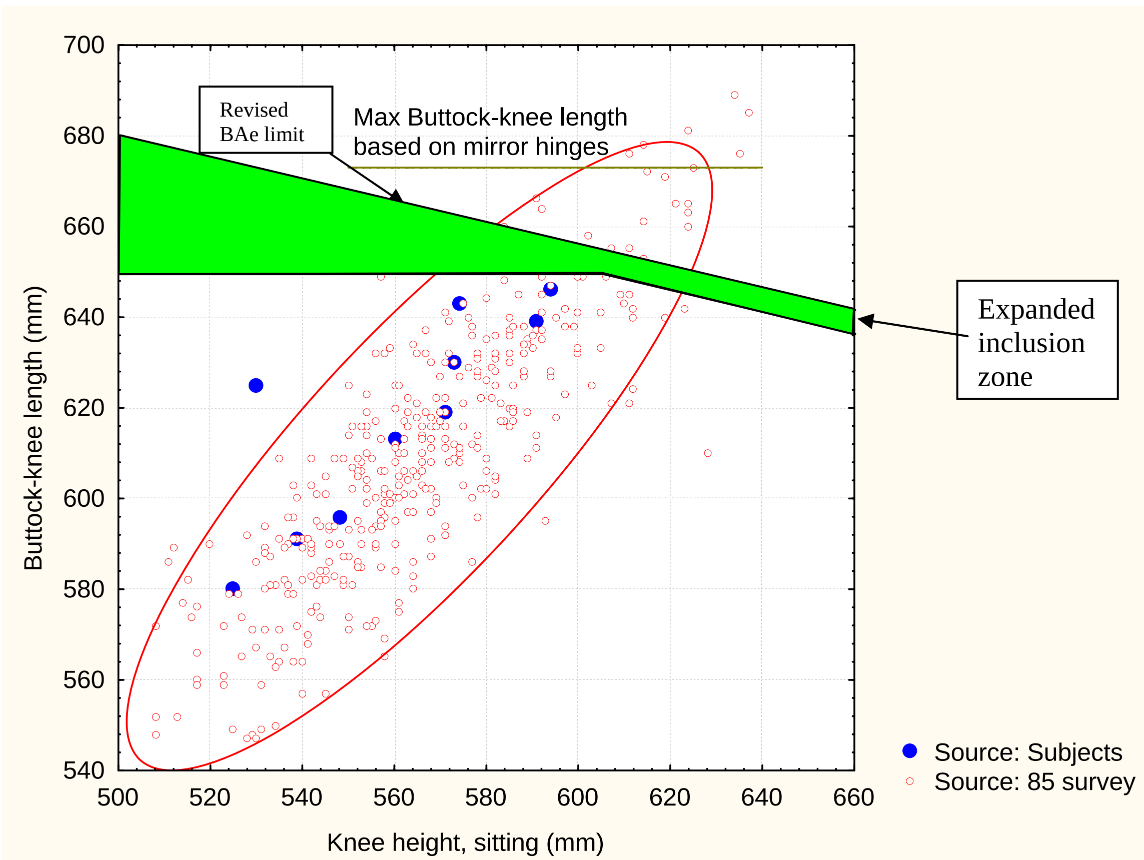

Figure 7 Option 2

5 Conclusions and recommendations

The results of the present study indicate that there is scope for a small increase in the current anthropometric limits for the Hawk. The extent of the anticipated increase in population accommodation depends on the option selected.

Option 1 proposes a change to the shin clearance limit and no change to the current ejection limit based on clearance of the front seat rear-view mirrors. The net effect of this option on overall cockpit accommodation would be negligible and not be worth implementing.

Option 2 proposes the same change to the shin clearance limit along with a change in philosophy with regard to what constitutes “aircraft structure”. By considering the mirror hinge as the closest aircraft structure, shin clearance becomes the only limitation with regards to leg length. The proposed limit puts an upper bound on Buttock-knee length that reduces the risk of contacting the mirrors in the event of an ejection. The net effect of Option 2 is to increase the admissibility of male pilots by approximately 2.5%.

Option 2 is recommended as a good “risk-measured limit” – as requested by 15 Wing – especially in light of the fact that the follow-on aircraft, i.e. the CF188, is much more accommodating.

It is also recommended that a screening system, such as the one in place in DRDC Toronto, be put in place at 15 Wing to measure and assess:

1. students that were admitted prior to the advent of the new pilot anthropometric selection standard

2. students that were screened more than one year prior to joining 15 Wing, as a precaution against changes in body shape and size during that time

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List of symbols/abbreviations/acronyms/initialisms

BAe	British Aerospace
BFOR	*Bona Fide* Occupational Requirements
CMB	Central Medical Board
DND	Department of National Defence
LPSV	Life Preserver Survival Vest
NFTC	NATO Flying Training in Canada
OPI	Office of Primary Interest
R&D	Research & Development
RAF	Royal Air Force
UK	United Kingdom

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In April 2006, the Canadian Forces (CF) transitioned to a new anthropometric selection standard for pilots. The new standard bases acceptance and rejection on whether individuals are physically compatible with the cockpits of all current aircraft; the previous standard was not aircraft-specific. As a result, cockpit compatibility assessments are not currently available for student pilots who were admitted under the previous standard and are now undergoing training. In July 2007, a pilot slated to train on the Hawk suspected he was too large for the cockpit. This prompted a series of events including an anthropometric assessment of current Hawk pilots and a review of the screening process and limits currently in place.

Ten pilots from 15 Wing and an external pilot were recruited to participate in a field trial designed to assess the shin clearance limits of the Hawk Mk 115. Clearance measurements between the shins and the main instrument panel were taken with the seat completely down or up, in summer and winter clothing. The minimum distance between the shins and the instrument panel was recorded with the rudder pedals in neutral and full left positions. In addition, the largest subject was assessed in the Hawk ejection trainer. The objective was twofold: 1) to observe the effect of seat movement on shin clearance and 2) to determine whether the trainer could be used as a cockpit compatibility assessment tool.

The results indicate that there is scope for a small increase in the current anthropometric limits with respect to shin clearance. However, the significance of this increase in terms of population accommodation depends on which option is retained. The recommended option would provide a risk-balanced limit that accepts a reduced ejection clearance zone between the knees and the rear-view mirrors. This would increase accommodation by about 2.5%. It was also determined that the ejection simulator was not sufficiently similar to the actual cockpit to be used as a cockpit compatibility assessment tool.

Résumé

En avril 2006, les Forces canadiennes (FC) ont adopté une nouvelle norme de sélection anthropométrique pour les pilotes. La nouvelle norme base l'acceptation ou le rejet des candidats selon qu'ils sont physiquement compatibles avec les postes de pilotage de la flotte; la norme précédente n'était pas aussi spécifique. En conséquence, la compatibilité des élèves pilotes présentement en formation n'est pas disponible pour ceux et celles qui ont été admis sous la norme précédente.

En juillet 2007, un pilote en voie d'être formé sur le Hawk soupçonnait qu'il était trop grand pour le poste de pilotage. Il a été envoyé à RDDC Toronto pour une évaluation en vertu de la nouvelle norme. Les résultats ont confirmé son incompatibilité. Cette décision a conduit à une série d'actions dans 15ème Escadre, y compris une évaluation de tous les pilotes de Hawk actuels afin d'identifier toute incompatibilité, un examen du processus de sélection, et une revue des limites actuelles.
Dix pilotes de la 15ème Escadre plus un pilote externe ont été recrutés pour participer à un essai sur le terrain pour évaluer les limites d'accommodation du Hawk Mk 115. Les tests ont consisté à mesurer la distance entre les tibias et panneau principal avec palonniers neutre ou plein gauche. Les essais ont été effectués avec le siège vers le bas ensuite et vers le haut, et en vêtements d'été et d'hiver. Des tests supplémentaires ont été effectués en utilisant le plus grand des sujets qui consistaient à effectuer des éjections simulées dans le simulateur d'éjection du

Hawk. L'objectif était double: 1) d'observer l'effet du déplacement du siège sur le tibia et 2) afin de déterminer si le simulateur pourrait être utilisée comme outil d'évaluation de compatibilité du poste de pilotage.

Les résultats indiquent qu'il est possible d'augmenter légèrement les limites anthropométriques actuelles. Toutefois, l'importance de cette augmentation en termes d'accommodation de la population dépend de l'option qui est retenue. L'option recommandée fournirait un risque équilibré en acceptant une diminution de la zone de dégagement entre les genoux et les rétroviseurs. Cela augmenterait l'admissibilité d'environ 2,5% pour les hommes (aucun effet sur les femmes). Il a également été déterminé que le simulateur d'éjection n'était pas suffisamment fidèle à la réalité pour être utilisé comme outil d'évaluation.

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